

Not dead yet

Despite its triumphs, string theory has begun to lose the public battle for hearts and minds. It's time to fight back, says **Sean Carroll**

A PHILANDERING string theorist is caught with another woman by his wife. "But darling," he pleads, "I can explain everything!"

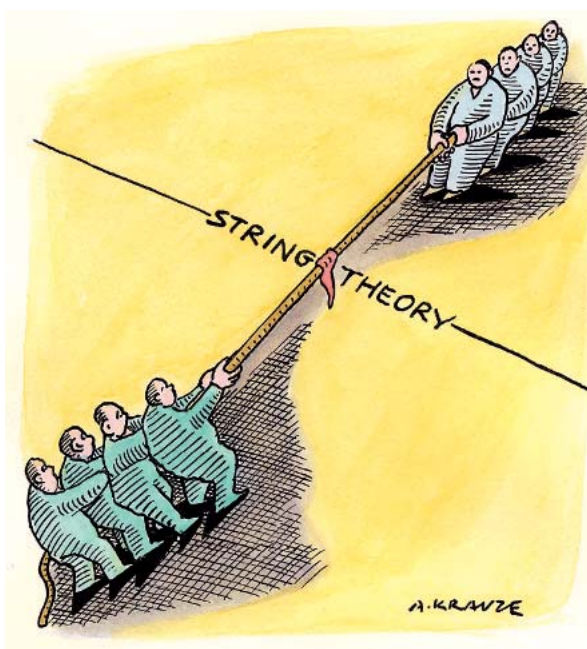
I didn't invent the joke; it appeared in the satirical magazine *The Onion*. The amazing thing is that people got it. The person on the street knows that string theory – the idea that the ultimate building blocks of nature are quantised loops of string, not point-like elementary particles – is our leading candidate for a theory that would, indeed, "explain everything".

Despite capturing the popular imagination, however, string theory has fallen on hard times lately, at least in the public arena. We read articles such as "Hanging on by a thread" (*USA Today*), "Theorists snap over string pieces" (*Nature*) and "The unraveling of string theory" (*Time*). Much of the scepticism can be traced to books by Lee Smolin and Peter Woit that appeared last year, but those aren't the only sources: pundits are increasingly ready to pronounce that string theory has failed in its ambitious project.

So is string theory in its last throes? No. String theorists are still being hired by universities in substantial numbers; graduate students are still flocking to the field. And it is still our most promising idea for linking quantum mechanics and gravity.

Never has so much effort been devoted to exploring an idea in physics without direct experimental tests. One big reason for this is the absence of experimental surprises in high-energy physics: for 30 years, the standard model has resisted all challenges.

That alone would not have been enough to coax theorists into thinking about the famously difficult problem of quantum gravity, however, if string theory hadn't presented a surprisingly promising approach. It was realised in the 1970s that string theory was a theory of quantum gravity, whether we liked it or not. Certain vibrating strings have the right properties to represent gravitons, carriers of the gravitational



force. Whereas head-on assaults on quantum gravity were running into dead ends, here was a quantum theory that insisted on gravity!

In the 1980s the triumph of the standard model was completed, and string theory was demonstrated to be a consistent framework. Physicists who would never have thought of devoting themselves to quantum gravity dived into string theory. True, there were five different versions of the theory, and they all lived in 10 dimensions. But all we needed was a way to squash those extra dimensions down to the four we know and love, and the connection to observation would be established.

That didn't happen, but the 1990s were nevertheless a boom time. The five versions of the theory were shown to be different manifestations of a single underlying structure, called M-theory. Tools were developed to tackle a famous problem introduced by Stephen Hawking in the 1970s – calculating the entropy of black holes. String theory gave precisely the right answer. More and more people became

convinced that something must be right about it, even if the connection to experiments remained elusive.

Since 2000, progress has slowed. In the mid-1990s it seemed there was a revolution every month; no longer. Instead of finding a unique way to go from 10 dimensions to four, we may now face 10^{500} possibilities. Maybe only a tiny number of those are anywhere close to the world we observe, so there are still concrete predictions to be made; maybe that's wishful thinking.

The truth remains, though. The miracles that first got people excited about string theory haven't gone away. We don't understand it very well: it's a collection of parts that show tantalising promise, but don't yet make a coherent whole. Nevertheless, it's a theory of quantum gravity, it fits everything we know about particle physics and it still provides startling new ways to think about space and time.

Meanwhile, spin-offs proliferate. Higher-dimensional "branes" have reinvigorated model-building in more conventional particle physics. The theory has provided many insights into mathematics. Cosmologists considering the early universe increasingly turn to it. And a new approach connects string theory to the dynamics of the quark-gluon plasma observed at particle accelerators.

Ultimately, string theory must make contact with data to remain interesting. Profound ideas, however, don't come with expiry dates: that contact might come in a year, 10 years, or a century. In the meantime, the relative importance of string theory within high-energy physics is bound to take a hit when the Large Hadron Collider opens later this year at the CERN nuclear physics lab near Geneva. Its results promise to take us beyond the standard model and give theorists new experimental puzzles to solve. String theory won't disappear, though. Gravity and quantum mechanics have to be reconciled, so theoretical physicists will continue to pursue string theory, at least until an even better idea comes along. Even then, the odds are good that something stringy will be part of the ultimate story. ●

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